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DEVELOPMENT OF A CORRIDOR SELECTION SYSTEM FOR FOREST ROAD LOCATION PLANNING

William O. Rasmussen
University of Arizona

February 1978

Final Report
for
Eisenhower Consortium for Western Environmental Forestry Research
Cooperative Agreement No. 16-526-CA
Rocky Mountain Forest and Range Experiment Station

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PREFACE

This is the first in a series of reports describing the various aspects of a computer software system developed to be used by a transportation planner as a tool in the delineation of recreational road corridors in a forest environment. Various environmental and social effects are taken into account in the selection of the corridor.

The current system is concerned mainly with selection of a corridor through a study area; the road may later be aligned in that corridor using some other program such as OPTLOC (Bennett, 1973) or FSRDS (George, 1975).

Introduction

Transportation systems analysis and corridor evaluation has typically focused primarily upon traffic volumes, design speed, capacity, structures, and spatial alignment. In urban and populated areas, there has been an increasing effort to consider social values with local and regional economic implications of alternative systems (Blood, 1973). However, there continues to be relatively little attention given to impacts on natural systems. A tendency seems to exist to relegate environmental impacts to an ancillary role in some transportation planning.

While the extreme complexity of assessing the impacts of road systems on the ecosystem is acknowledged, this should not be an excuse for meager considerations of environmental impacts. The state-of-the-art in land-use planning, ecosystem modeling, and other environmental assessment methodologies is advancing rapidly (Rasmussen, et al., 1978). Computer-based techniques can provide the transportation system planner with the ability to select specific environmentally desirable road corridor locations. Proper application of these planning tools could insure appropriate consideration of environmental impacts, while remaining consistent with the engineering and economic constraints that must guide the transportation planning process (USDA Forest Service 1973).

The following study explores the use of a computer-assisted method for selecting and evaluating transportation corridors in forest environments. The basic approach is to use computer-mapping procedures to display, interact and evaluate the many environmental, engineering, and economic variables that determine location and alignment of a forest road. Related methods have been discussed in several contexts (Turner, 1968). Miller and Nieman (1972), for example, employed a similar approach, however, they relied

exclusively on professional judgment to quantify the economic and environmental implications of corridor alternatives. The approach employed in the present study is based upon objective assessment procedures, with more explicit computer mapping and evaluation techniques.

While the present study is centered around the siting of a specific forest road, the primary purpose of the report is to illustrate a general computer-assisted corridor selection methodology. Application to an actual forest area provides a concrete and practical context for illustrating the computer-assisted procedures.

Study Area

The study area, selected in consultation with USDA Forest Service personnel, was the South Thomas Creek Experimental Watershed, located on the Apache-Sitgreaves National Forest in northeastern Arizona.

This watershed encompasses 562 acres of mixed conifer forest. The terrain is relatively steep, ranging from an elevation of 8400 to 9200 feet above sea level. Average annual precipitation is 28 inches. Douglas-fir, white fir, and ponderosa pine are the most abundant overstory species, while white pine, Engelmann spruce, blue spruce, corkbark fir, and quaking aspen are also found. Tree basal area averages 180 square feet per acre, while saw-timber volume averages 22,430 board feet per acre.

South Thomas Creek had never been logged at the time of the study. Much of the timber was mature or overmature, and there was a considerable volume of downed wood. Annual runoff averages 160 acre-feet. The watershed provides habitat for wildlife and some forage for domestic livestock.

Economic and Environmental Impact Indices

The Forest and Rangeland Renewable Resources Planning Act of 1974 suggests a balance should exist between economic and environmental quality factors for all programs impacting forest or rangeland (16, USDA 1601, 1974). This act implies objective measures of economic and environmental benefits and costs should be an integral part in the selection of forest road corridors. In this present study, two types of quantitative indices have been developed for illustration. Those presented represent aspects of economic and scenic quality factors relevant to the design of a recreational road corridor.

For the development of the economic indices, we adopted the road design standards and average costs of the Southwest Region, USDA Forest Service for an 18-ft. wide, graded and drained forest road appropriate for the South Thomas Creek study area (USDA Forest Service, 1973). While this approach is not currently being used by the Forest Service it does give a relative cost variation in road construction at various locations on a study area. For planning purposes, the relative variations in cost, rather than absolute current costs is used for road corridor solution. A refined cost value may be arrived at through the use of more sophisticated road siting programs such as FSRDS (George, 1975). Approximate construction costs and their relationship to the physiographic factors on South Thomas Creek are summed from individual tables of clearing cost per mile, excavation cost per mile, and culvert cost per mile. The array showing total cost per mile as a function of slope and stand density is presented in Table 1.

This list of cost factors is not exhaustive. For example, other costs, such as the cost of road maintenance, could have been included. Similarly, some benefits, such as the revenues from the sale of the cleared timber,

could also have been included. However, the present economic measure is sufficient to illustrate the corridor selection procedure.

Data Handling

High altitude color aerial imagery of the watershed was used to delineate the timber stands. The original imagery at a scale of 1:120,000 was enlarged to a scale of 1:60,000 to allow more accurate delineation of stand boundaries. Five stands were found to cover the area. After the stands had been delineated on the photo, several ground control points were located on the photo to allow timber stand boundaries to be digitized directly from the photo. Accurate registration of the photo allowed the digitized area (from the imagery) to correspond to the same area digitized from a topographic map such that both data sets could be manipulated in the computer.

A topographic map of the watershed was digitized by a point digitizer which transformed the mapped elevation data to a numerical form which could be manipulated in the computer. The digitized topographic data were comprised of irregularly spaced elevation points. These data were interpolated to produce values at all locations on a regular spatial grid, representing the study area, using the program SYMAP (Dougenik and Sheehan, 1975). SYMAP was also used to fill in another regularly spaced array showing which timber stand each array grid cell belonged to. The regularly spaced elevation array was used as input to the program SLOPE in order to produce the average slope of the topography at each cell location in the array. This program mathematically fits a tangent plane over each cell in the array such that the sum of the squares of the deviations between the plane and the elevation of the four surrounding cells is a minimum. The data arrays of surface slope and timber stands are presented in figures 2 and 3. The program SLMATH was used to graphically display the numerical values in these arrays.

The legends of the computer printer maps generated by SLMATH contains information regarding the comprehension of these maps. The total range of slope values was divided into ten intervals shown in the legend. For each interval the range in data values and the symbolism used to represent that range on the map are given. The number of cells on the map in each value range is presented along with three measures of the surface area of cells falling into those ranges. The percent of the entire area having data values in each of the data ranges is also presented in the legend. In general, darker appearing symbols are associated with higher data values.

The economic information presented in Table 1, showing cost of road development per mile to be a function of slope and average size of the timber, was incorporated into a subroutine of the program SLMATH. This sub routine was then used with the slope and timber stand arrays of data. The result or output from this program was an array of data values representing, for each cell or element of the watershed, the average cost of road development per mile, when slope and stand characteristics associated with that cell are encountered.

Figure 4 illustrates the spatial distribution of the economic factors for South Thomas Creek. This map is derived from slope and timber data for the study area. For any given location, the lower the cost per mile the lighter the grey shading of the symbols used on the map. As the legend to Figure 4 indicates, economic costs of road construction per mile range from $8310 to $33,218.

Scenic Quality Indices

To select and evaluate alternative road corridors on the basis of scenic quality criteria, a detailed representation of changes in scenic beauty from point-to-point across the study area was required. While a

number of procedures for assessing scenic beauty have been proposed and to some extent applied (Arthur and Boster, 1976), few provide the degree of precision necessary to map variations over a specific natural landscape. For this study, the Scenic Beauty Estimation (SBE) method developed by Daniel and Boster (1976) was utilized.

Separate SBE values were obtained for 200 sample points across the Thomas Creek study area (Anderson and Daniel, 1977). At each point a sequence of four color slides, 90 degrees apart, were taken with the first photo randomly oriented. Separate sets of 120 slides were randomly sampled from a total pool of 800 slides and shown in random orders to independent groups of college student volunteers. Based on the four separate slides, each judged by a minimum of 30 observers, mean SBE values were calculated for each sample point. These values constituted the input data for the computer mapping program. Figure 5 shows the distribution of interpolated scenic beauty values for South Thomas Creek.

Other Indices

Other relevant factors could be included in future studies. For example, the impact of forest roads on erosion is an important factor that should be considered. However, for the purpose of this study only economic and scenic quality indices were utilized.

Composite Mapping

A scenic beauty map of the area was produced by the computer. This map used the computed values for sceninc beauty at selected sample points as input. The program SYMAP interpolated these values into uniform values of a spatial array. The data were inverted and expanded to have a data

range roughly comparable to that of the economic data. This data transformation was conducted in order to allow the scenic beauty data to be added to the economic data in the composite mapping process.

Compositing of maps is the assigning of weights to each map, and adding the weighted maps or data arrays together cell by cell. The individual maps usually have their data transformed so as to lie in the same numeric ranges. Weights are then assigned to the individual maps to represent the relative importance given to each topic. If one map is felt to be three times as important as another then a weight of .75 would be multiplied with all values in the first data array while a value of .25 would be multiplied with all elements of the second data array. The array which represents the cell-by-cell summation of the weighted data arrays is the composite map data array. The entire operation is a quantitative means to add apples and oranges. When compositing is done with the topics of scenic beauty and economic costs the values of the weights are given by a pair of numbers. The first value is the weight assigned to the scenic beauty data array and is multiplied by all elements of that array while a similar operation is performed on the economic data array by the second value of the pair.

Road Path Delineation

Two points were selected as terminal points of a road which was to be located on the watershed. These terminal points are called A and B on Figure 4. This map shows for each cell the cost of road construction per mile as if that cell were to be increased in size while continuing to have the same associated data characteristics. A road was manually located on the economic surface in such a fashion as to minimize the total cost of construction, and follow local laws in construction cost. The sum of all cell values which the road passed over was computed along with the average cost

per cell. The path which had the lowest value for total path cost was called the "best" road location (path 2). A path is approximated by a series of cells which represent cells a road or line would pass through.

The scenic beauty map is presented in Figure 5. This map also has a road located on it between the terminal points of A and B. The data presented in this map has been transformed to roughly the same range as the economic data. A path was manually located on this surface so as to maximize the total scenic beauty of the cells traversed as well as maximize the local esthetic experience. Maximization of the scenic beauty values implies minimization of the cell values traversed as the scenic beauty scale has also been reversed; high values on the surface represent areas that would be relatively displeasing to an observer in the area. The road was located on this surface as in the case of the construction surface (path 1). The sum of the cell values traversed was computed and is presented along with the average cost for each cell value in Table 2.

The sum and average of all cell values traversed by a road path located using only economic considerations is represented by path 1, of Table 2. Path 2 is derived by locating a road on the watershed where maximizing total scenic beauty is the only constraint. In general, there might be some combination of these two factors used for the location of the road. Three combinations of the surfaces of economic costs and scenic beauty costs were utilized for the manual location of roads between the same terminal points. The composite surfaces were produced by compositing with the following weight pairs assigned to the individual factors of scenic beauty and economic costs: (.25, .75), (.50, .50), and (.75, .25). These surfaces and associated paths are presented in Figures 6, 7, and 8.

A path location was manually delineated on each of these three surfaces such as to have the total value of the cells traversed a minimum while going through local lows. These paths are shown on the composite surfaces and called respectively path 3, path 4, and path 5. The location of each of these paths were further delineated on the original economic and scenic beauty surfaces. The total value of the economic cells traversed and the average cell value in the path were computed for each of the paths. Similar computations were performed for the three paths on the scenic beauty surface. These values are presented in Table 2. This table shows the trade-off in total and average construction cost opposed to the total scenic beauty costs as the two paths are selected on surfaces showing gradations in the mix of economic to esthetic constraints being used. One extreme is location of a road based only on economic costs (path 1), the other extreme is positioning of a road based on scenic beauty values alone (path 2). Between the two extremes are three mixes of the two quantities.

The path manually selected on the economic surface alone, path 2, has the lowest average economic cost of all the paths delineated. However, the cost of this path in terms of average scenic beauty units is the highest of all paths. The reverse is true for the path manually delineated on the scenic beauty surface, path 1. This path had the lowest of all average scenic beauty costs but had the highest average economic cost.

The total path costs through either the scenic beauty or economic data arrays track closely with the average cost values.

The total path value for a long path which goes through only cells with very low values could easily be greater than another path which contains fewer cells of higher value. The location of a path through only cells with low values must be tempered with the selection of a path that is as short

as possible. The optimum path is selected such that it passes through cells which have the lowest values possible and the total length is a minimum. Thus, it may be advantageous to have high values for a part of the path if the total path value will be reduced. The manual placement of the path allows it to be positioned in locations where tunneling or passing through areas of high values is an appropriate procedure. This may allow the overall or total path to have a lower value than other paths which do not pass through areas with high data values. For operations of this nature, manual delineation of a path may be superior to an automated approach.

The criteria used in the manual placement of the paths were that they were to go through local minima as much as possible and also have the total path value minimal. In the placement of a corridor on the cost surface the operator's mind selected locations which had the lowest local values but could not adequately sum up the cells to determine if the total value of tha path is lower than some other. For selection of the lowest total value corridor or path, the computer is very beneficial. It can determine the lowest total cost path from several possibilities with ease where the human would not easily be able to locate the path which is lowest in total value from several possibilities. This biasing on the part of the human operator in the placement of a path on the cost surface towards locating it in a location which minimizes only local or neighborhood values will be addressed in future versions of the corridor selection system.

Prediction of Path Average Cost

Using the data extremes for average cost per cell based on either scenic beauty or economic data alone, functions can be used to predict the average cost for paths through composite surfaces of some mix of these parameters. The average economic value for the path on an economic map (path 1)

may be represented by E_e. Similarly, a value for the average economic value for a path on the scenic beauty surface (path 2) may be represented by E_s. A linear function, y_e, for prediction of average economic path values for some mix of scenic beauty and economic data with a weighting pair given by (w_1, w_2) may be represented by

$$y_e = E_s w_2 + E_e w_1 \qquad (1)$$

where $w_1 + w_2 = 1.0$

Using the numerical values found in Table 1 for E_e and E_s, equation (1) is then of the form

$$y_e = 16,194\ w_2 + 11,974\ w_1 \qquad (2)$$

A similar equation may be written for predicting average scenic beauty path values for a path on a composite surface of weighting (w_1, w_2), such as

$$y_s = 9,478\ w_2 + 13,462\ w_1 \qquad (3)$$

Equation (2) is plotted against measured values of average economic cost per path cell in Figure 9. Figure 10 shows average scenic beauty cost per cell for the five paths plotted with the prediction function y_s. From the two figures, it is apparent that the two functions fit the data only loosely. However, they could be used if one were in need of relative differences in average costs for paths on composite surfaces of economic and scenic beauty if time and resources were not available to use the computer.

Total path costs for the five paths showed too much variation to be fitted with an equation based on only five points.

Road Corridor Delineation

The corridor containing as one possible road, the one selected using the manual technique, is to be used for planning purposes. The road corridor is developed by widening the path to several cells in width.

In practice, one means used to represent the corridor has been to outline it on a topographic map of the area. The path derived from the previous analysis is first drawn on the map and then widened to form a corridor. The corridor is then input to the computer with the program SYMAP from a delineation of its boundaries, similar to the inputting of the stand boundaries from the aerial photo.

The corridor data array, stored in the computer, has a value of 1.0 assigned to all cells contained in the corridor with a value of 0.0 given to all cells outside. Multiplication of the corridor data array, cell by cell, with a topographic array results in only topographic cells in the corridor having nonzero values. The topographic data array is thus reduced such that only cells in the corridor have values. Such a data array is used as input to other road location analysis programs such as OPTLOC (Bennett, 1973) or FSRDS (George, 1975). The system outlined here is used only to define the road corridor; other programs are to be used to locate and align the road within the corridor.

Summary and Conclusion

A methodology for incorporating economic and aesthetic criteria within a forest-road corridor selection process has been described. The methodology utilizes computer graphics techniques to store, analyze, interact, and display information needed for corridor decision-making. Economic costs are based on an accounting of the total dollar costs of each alternative. Scenic beauty estimates, based on a systematic public participation process, are used to quantify esthetics. Trade-offs between economic and esthetic factors are readily displayed by developing corridor alternatives based on both economic and esthetic criteria. Although objective procedures are used to quantify economic and esthetic impacts, human judgment is still

required in this methodology to assign the relative weights, or importance, to alternative criteria before the maps are composited in the production of a suitability surface for a recreational road.

A technique has been presented to delineate a path between two terminal points in a spatial data array representing some combination of economic and scenic beauty costs of road construction.

Path costs in terms of total cost and average cost per cell for equivalent paths through the economic or scenic beauty arrays were computed for five paths. One path was manually located on a purely economic surface, while another was located on a scenic beauty cost surface. The other three paths were manually located on surfaces representing mixes of economic and scenic beauty costs.

Equations were developed to predict the average scenic beauty or economic cost per cell for a path through a surface representing some mix of the two parameters.

A road corridor through a topographic data array is produced by widening the path manually delineated on one of the cost surfaces. The topographic data array, representing only cells in the road corridor, is used as input to other computer programs for final alignment of a road within the corridor. The current system uses scenic beauty as an example of an additional parameter to economics which can be taken into account in the location of a road corridor within a study area. The total system has been designed in such a way that other considerations such as potential sediment production and visibility may be taken into account in later versions. Thus, an important feature underlying this computer-assisted design process is an objective procedure for bringing together economic, esthetic, and other factors in the context of forest road location planning.

Acknowledgements

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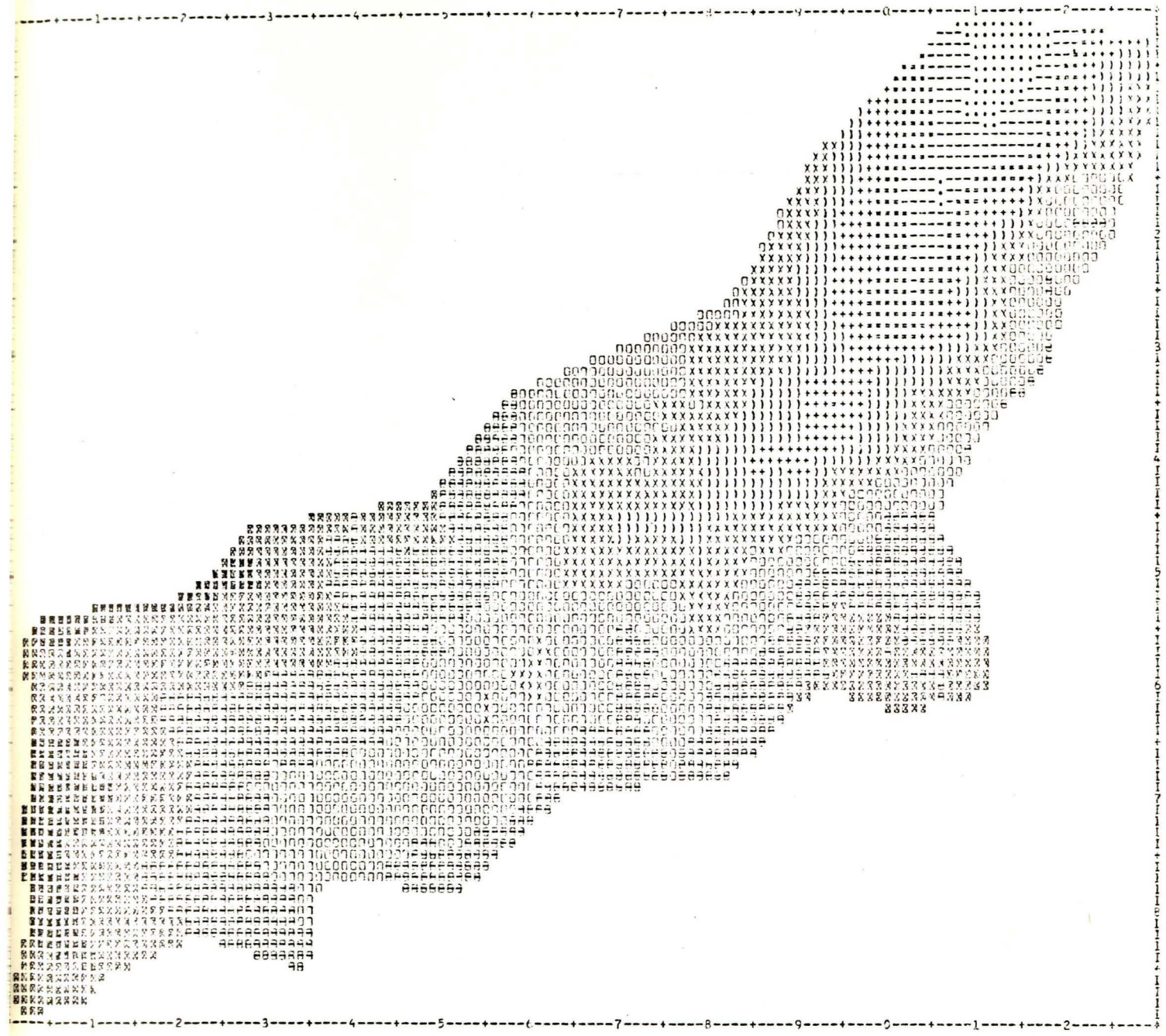


THOMAS CREEK ELEVATION MAP

BOVE MAP HAS A MINIMUM OF: 8400.000
MAXIMUM OF: 9200.000

VALUE RANGE FOR EACH LEVEL

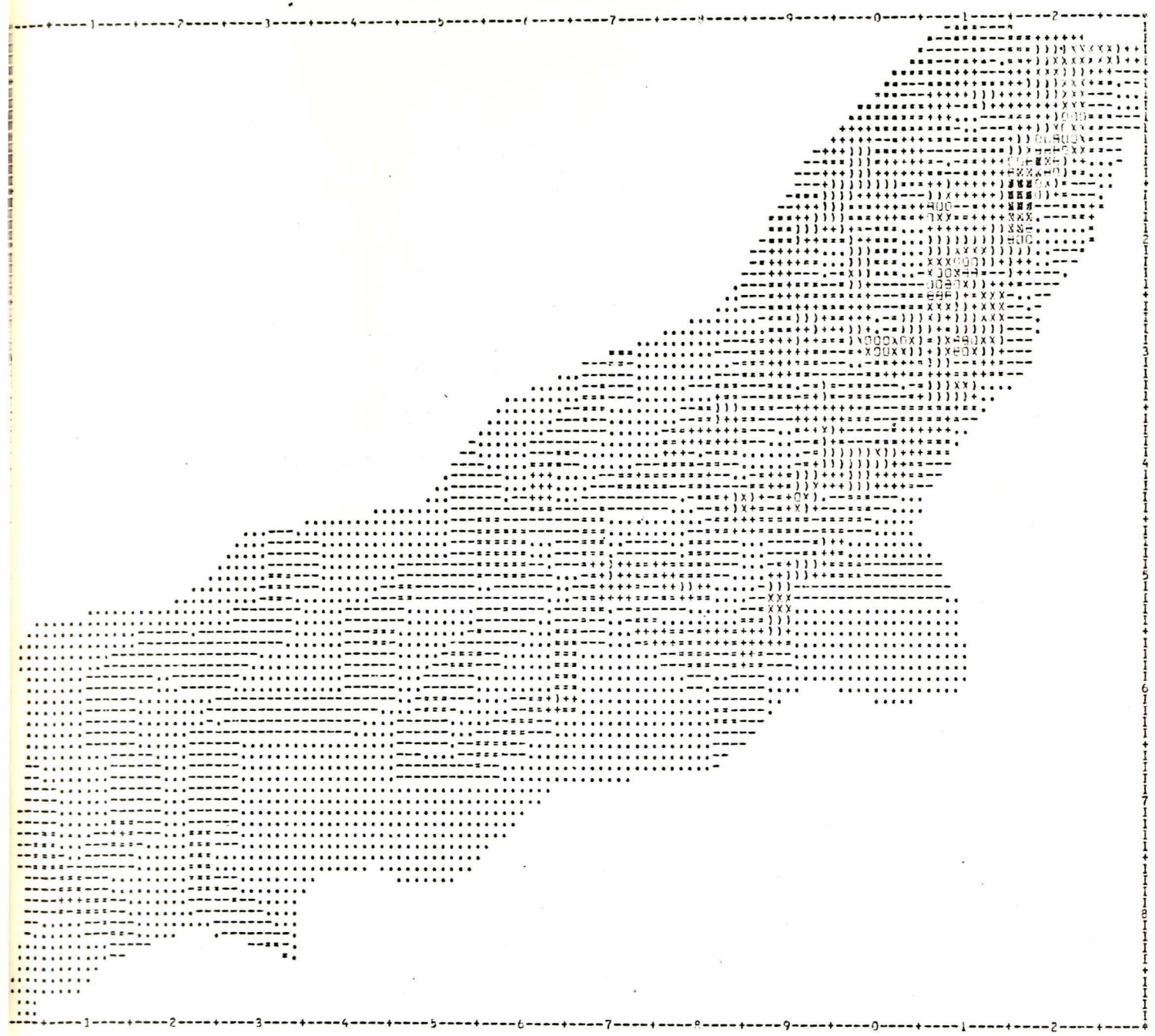
INIMUM	8400.000	8480.000	8560.000	8640.000	8720.000	8800.000	8880.000	8960.000	9040.000	9120.000
AXIMUM	8480.000	8560.000	8640.000	8720.000	8800.000	8880.000	8960.000	9040.000	9120.000	9200.000
ELLS	71	154	179	233	345	565	1267	1123	789	200
CREAGE	6.46	18.34	21.32	27.75	41.09	67.29	143.76	133.76	93.97	23.82
ECTARS	3.42	7.43	8.63	11.23	16.64	27.24	58.20	54.15	38.04	9.64
Q.MILES	.0132	.0287	.0333	.0434	.0642	.1051	.2246	.2090	.1468	.0372
ERCENT	1.46	3.16	3.68	4.79	7.09	11.61	24.80	23.08	16.21	4.11

SYMBOLS FOR DATA LEVELS

TOTAL AREAS: 4866. CELLS 579.57 ACRES 234.63 HECTARES .91 SQUARE MILES

THIS MAP PRE

Figure 1. South Thomas Creek watershed, located within the Apache-Sitgreaves National Forest, Arizona.



THOMAS CREEK SLOPE MAP

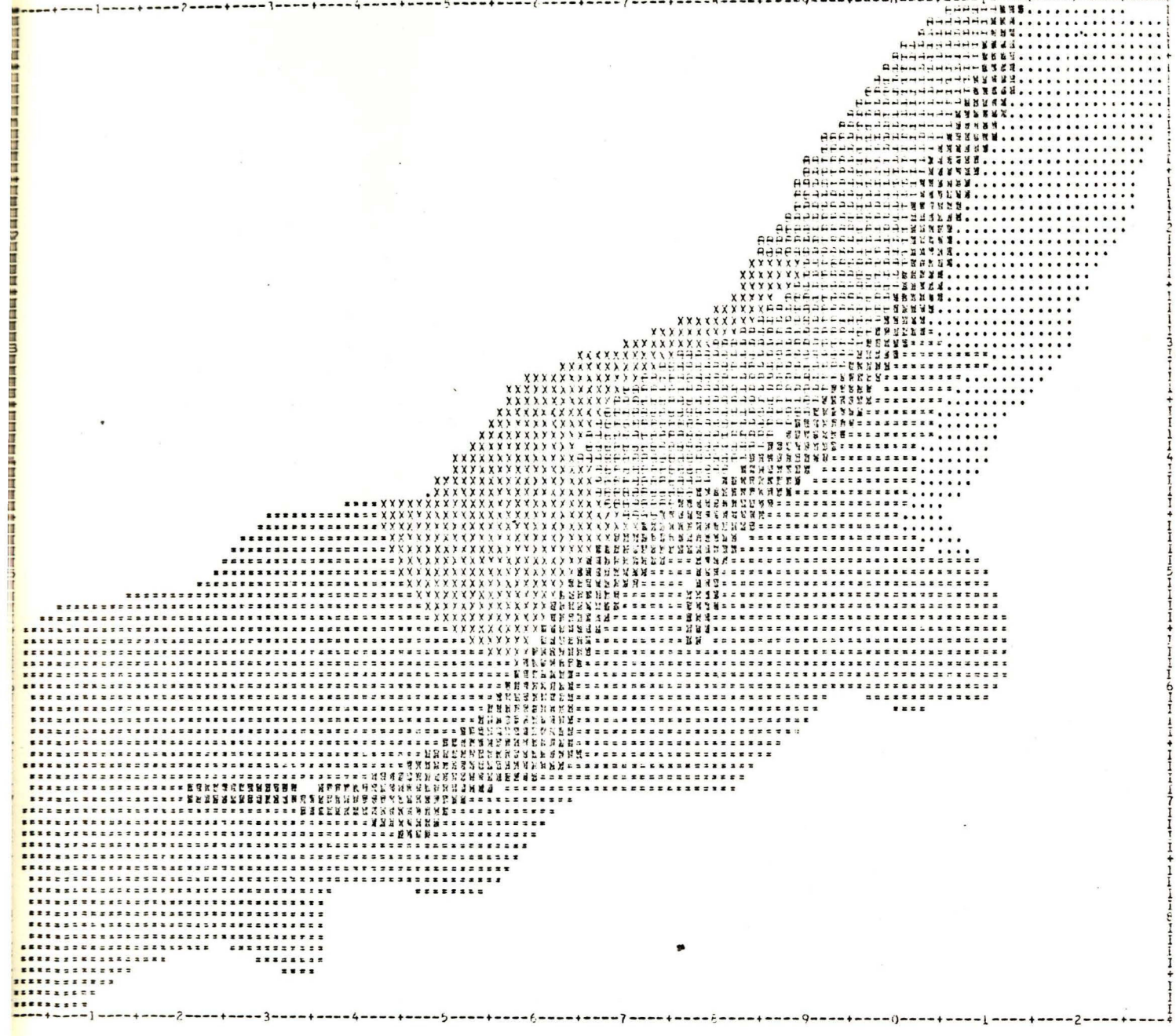
BOVE MAP HAS A MINIMUM OF: 0.000 MAXIMUM OF: .464									
VALUE RANGE FOR EACH LEVEL									
INIMUM	0.000	.046	.093	.139	.186	.232	.279	.325	.372	.418
AXIMUM	.046	.093	.139	.186	.232	.279	.325	.372	.418	.464
ELLS	1911	1338	676	398	215	84	36	20	10	10
CRAGE	227.61	159.36	80.52	47.40	25.61	10.00	4.29	2.38	1.19	1.19
ECTARS	92.14	64.52	32.60	19.19	10.37	4.05	1.74	.96	.48	.48
Q.MILES	.3556	.2490	.1258	.0741	.0400	.0156	.0067	.0037	.0019	.0019
ERCENT	40.68	28.48	14.39	8.47	4.58	1.79	.77	.43	.21	.21

SYMBOLS FOR DATA LEVELS

OTAL AREAS: 4698. CELLS 559.56 ACRES 226.53 HECTARES .87 SQUARE MILES

HIS MAP PREPARED

Figure 2. Slope map of South Thomas Creek



THOMAS CREEK TIMBER MAP

BOVE MAP HAS A MINIMUM OF: 1.000
MAXIMUM OF: 5.000

VALUE RANGE FOR EACH LEVEL

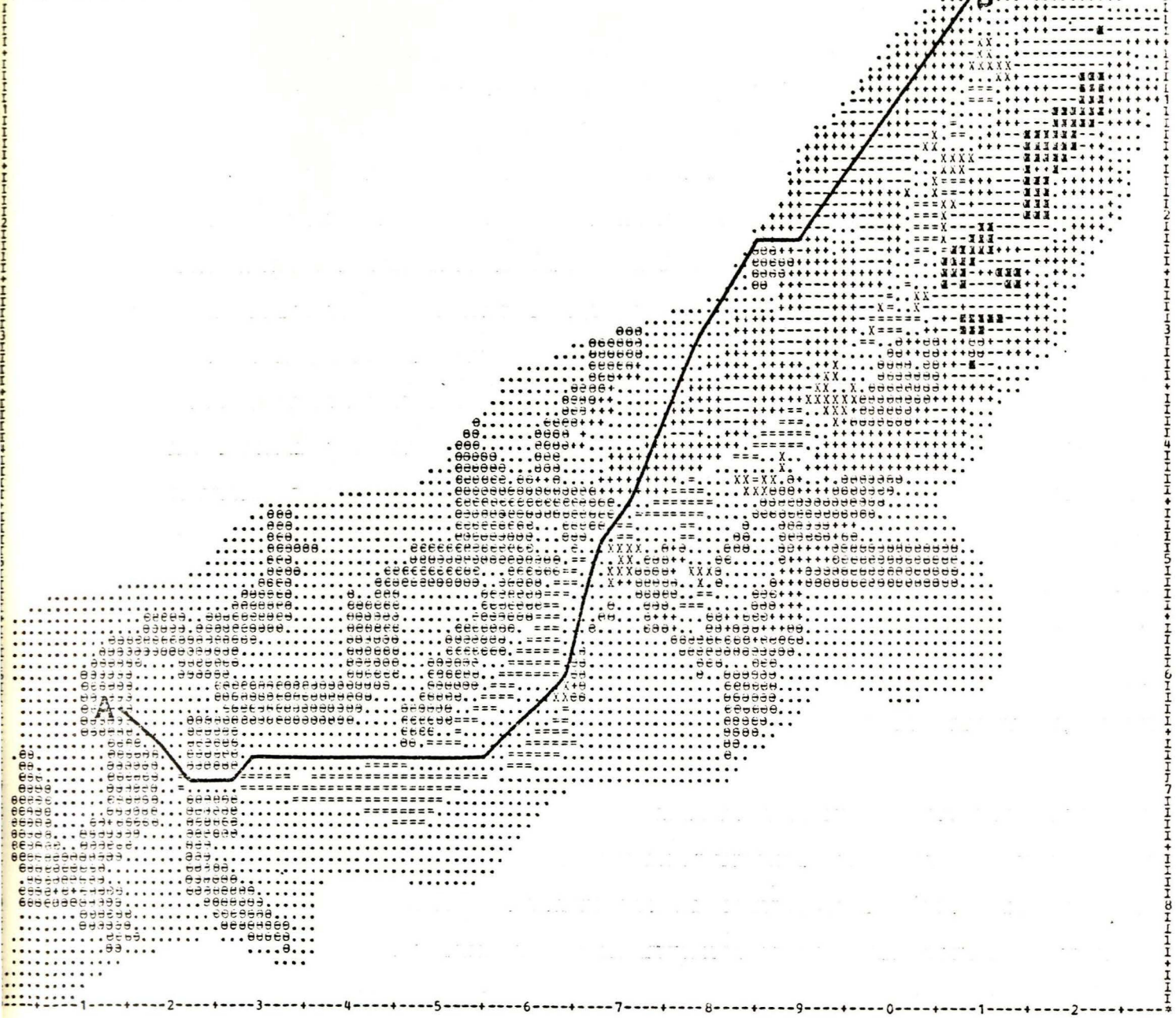
INIMUM	1.000	1.400	1.800	2.200	2.600	3.000	3.400	3.800	4.200	4.600
AXIMUM	1.400	1.800	2.200	2.600	3.000	3.400	3.800	4.200	4.600	5.000
ELLS	617	0	2608	0	0	487	0	642	0	631
CREAGE	73.49	0.00	310.63	0.00	0.00	58.00	0.00	76.47	0.00	75.16
ECTARS	29.75	0.00	125.75	0.00	0.00	23.48	0.00	30.96	0.00	30.43
.MILES	.1148	0.0000	.4854	0.0000	0.0000	.0906	0.0000	.1195	0.0000	.1174
ERCENT	12.38	0.00	52.32	0.00	0.00	9.77	0.00	12.88	0.00	12.66

SYMBOLS FOR DATA LEVELS

OTAL AREAS: 4985. CELLS 593.74 ACRES 240.37 HECTARES .93 SQUARE MILES

HIS MAP PREPARED F

Figure 3. Timber stands on South Thomas Creek.



THOMAS CREEK ECONOMIC MAP

BOVE MAP HAS A MINIMUM OF: 8310.000
MAXIMUM OF: 33218.000

VALUE RANGE FOR EACH LEVEL

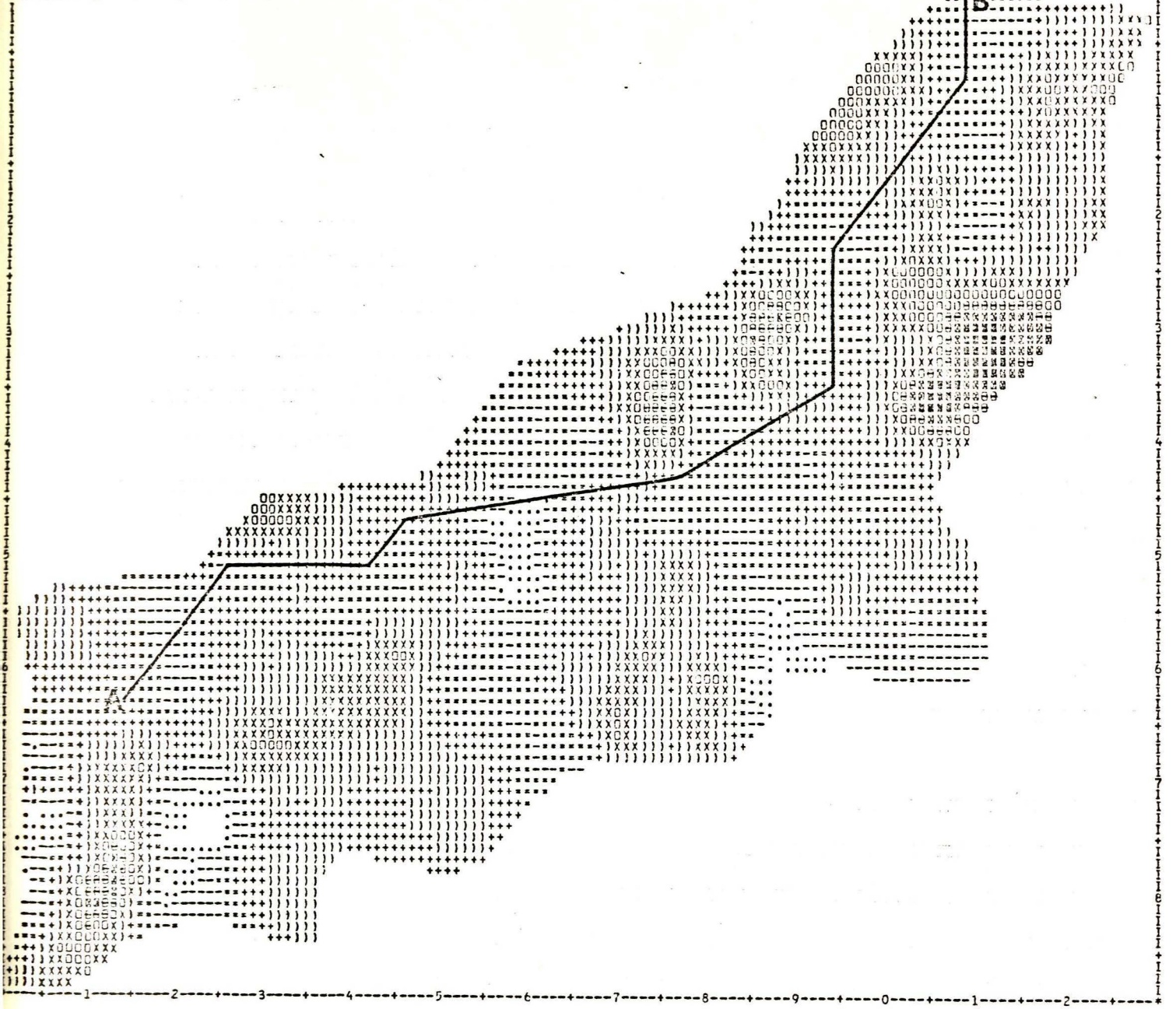
INIMUM	8310.000	10800.800	13291.600	15782.400	18273.200	20764.000	23254.800	25745.600	28236.400	30727.200
AXIMUM	10800.800	13291.600	15782.400	18273.200	20764.000	23254.800	25745.600	28236.400	30727.200	33218.000
ELLS	2361	346	265	672	0	76	0	1180	0	85
CREAGE	281.21	41.21	31.56	80.04	0.00	9.05	0.00	140.54	0.00	10.12
ECTARS	113.84	16.68	12.78	32.40	0.00	3.66	0.00	56.90	0.00	4.10
.MILES	.4394	.0644	.0493	.1251	0.0000	.0141	0.0000	.2196	0.0000	.0159
ERCENT	47.36	6.94	5.32	13.48	0.00	1.52	0.00	23.67	0.00	1.71

SYMBOLS FOR DATA LEVELS

TAL AREAS: 4985. CELLS 593.74 ACRES 240.37 HECTARES .93 SQUARE MILES

IS MAP PRE

Figure 4. Road construction cost per mile on South Thomas Creek, with location of optinum road path between terminal points A and B.



THOMAS CREEK SCENIC QUALITY MAP

ABOVE MAP HAS A MINIMUM OF: 0.000
MAXIMUM OF: 33000.000

VALUE RANGE FOR EACH LEVEL

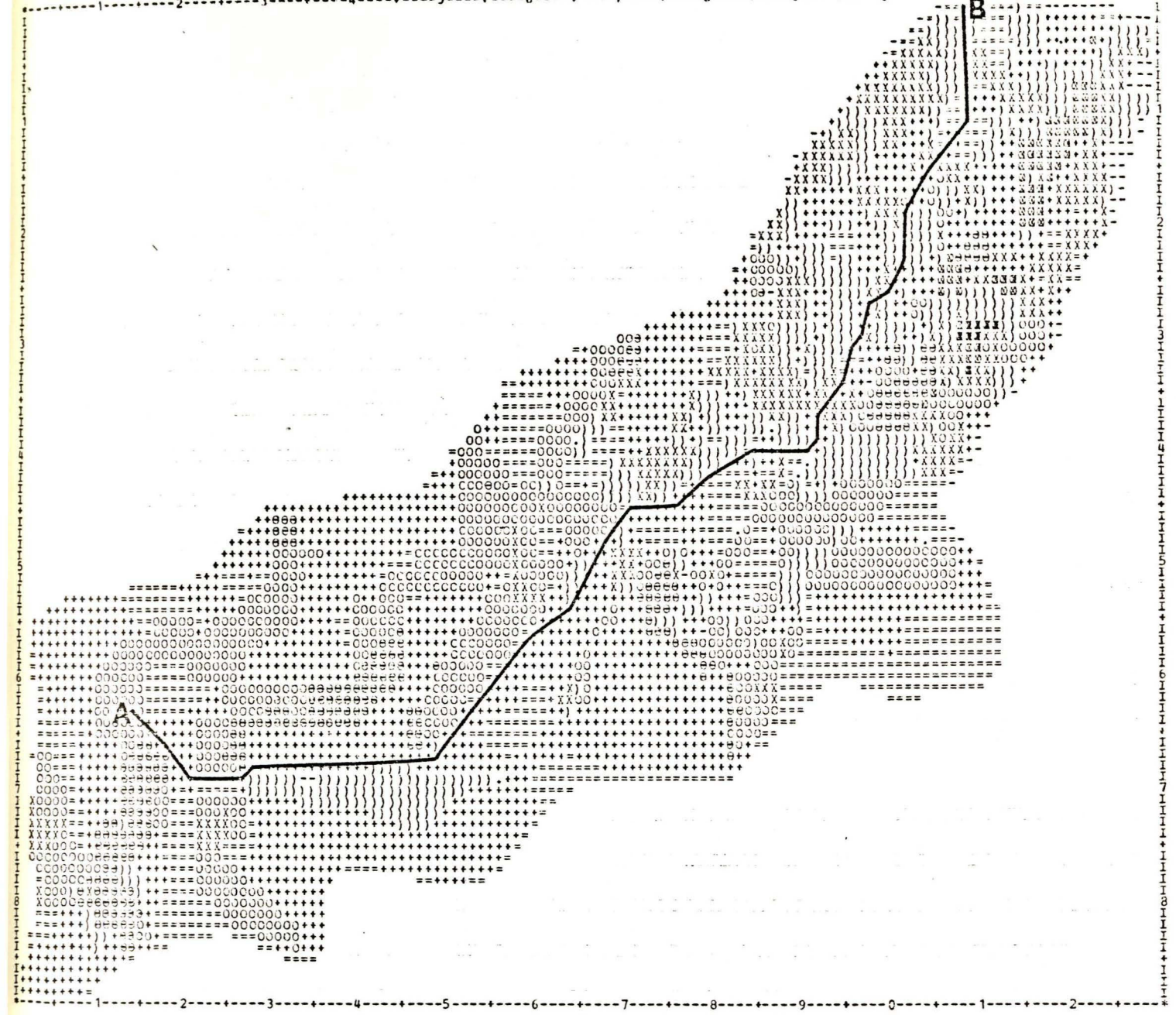
MINIMUM	0.000	3300.000	6600.000	9900.000	13200.000	16500.000	19800.000	23100.000	26400.000	29700.000
MAXIMUM	3300.000	6600.000	9900.000	13200.000	16500.000	19800.000	23100.000	26400.000	29700.000	33000.000
CELLS	131	371	1033	1222	1098	555	219	84	60	33
ACREAGE	15.60	44.19	123.04	145.55	130.78	66.10	26.08	10.00	7.15	3.93
HECTARS	6.32	17.89	49.81	58.92	52.94	26.76	10.56	4.05	2.89	1.59
SQ.MILES	.0244	.0690	.1922	.2274	.2043	.1033	.0408	.0156	.0112	.0061
PERCENT	2.73	7.72	21.49	25.43	22.85	11.55	4.56	1.75	1.25	.69

SYMBOLS FOR DATA LEVELS

TOTAL AREAS: 4806. CELLS 572.42 ACRES 231.73 HECTARES .89 SQUARE MILES

THIS MAP PREPAR

Figure 5. Scenic beauty map of South Thomas Creek with location of optinum road path between A and B.



THOMAS CREEK COMPOSITE MAP
(ECONOMIC=.75 SCENIC QUALITY=.25)

ABOVE MAP HAS A MINIMUM OF: 0.000
MAXIMUM OF: 33000.000

VALUE RANGE FOR EACH LEVEL

MINIMUM	0.000	3300.000	6600.000	9900.000	13200.000	16500.000	19800.000	23100.000	26400.000	29700.000
MAXIMUM	3300.000	6600.000	9900.000	13200.000	16500.000	19800.000	23100.000	26400.000	29700.000	33000.000
CELLS	10	59	751	1869	594	440	918	269	73	8
ACREAGE	1.19	7.03	90.44	222.61	70.75	52.41	109.34	32.04	8.69	.95
HECTARS	.48	2.84	36.69	90.12	28.64	21.22	44.26	12.97	3.52	.39
SQ.MILES	.0019	.0110	.1416	.3478	.1105	.0819	.1708	.0501	.0136	.0015
PERCENT	.20	1.18	15.22	37.37	11.88	8.80	18.36	5.38	1.46	.16

SYMBOLS FOR DATA LEVELS

TOTAL AREAS: 5001. CELLS 595.65 ACRES 241.14 HECTARES .93 SQUARE MILES

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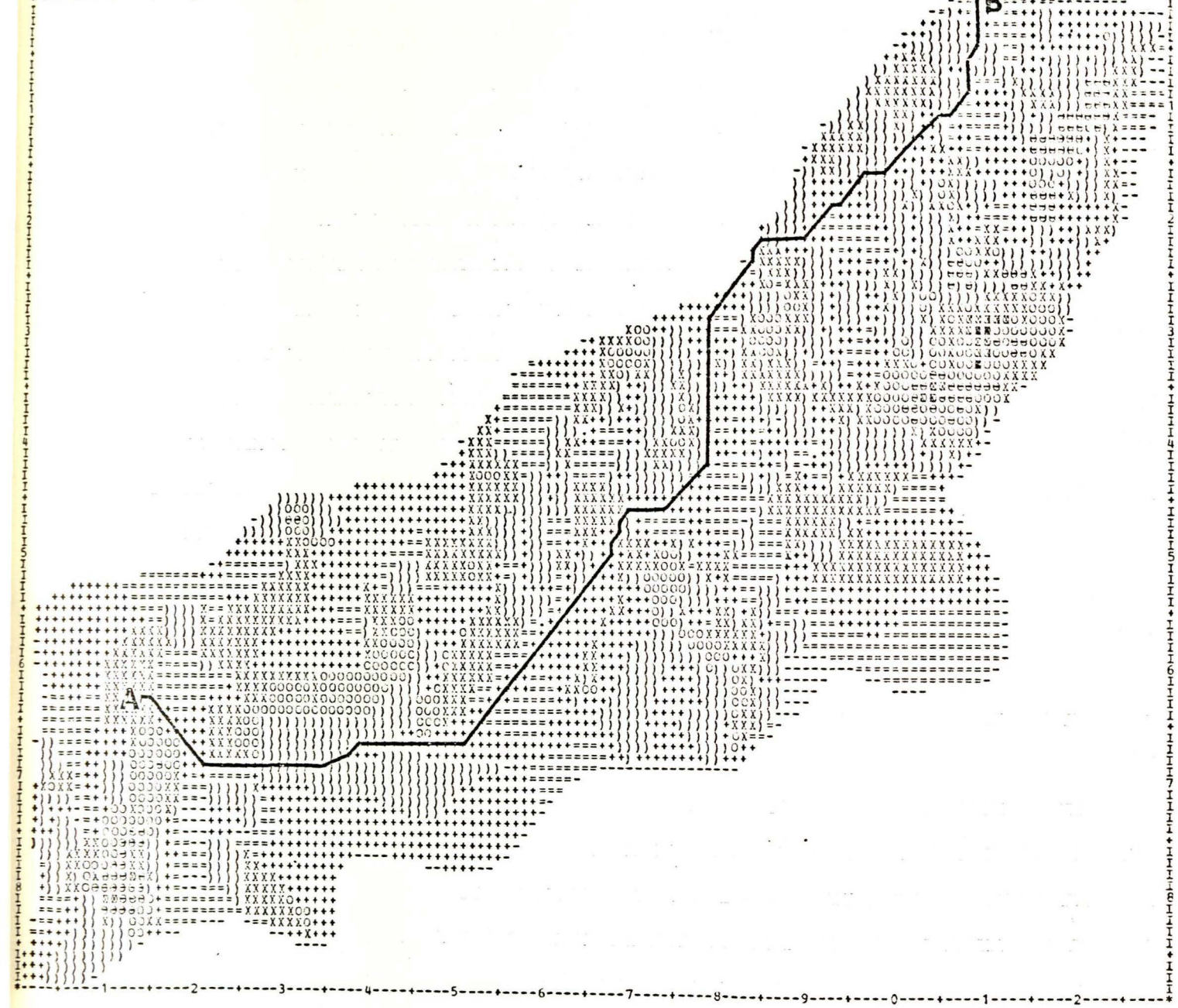
Figure 6. Composite map of .25 scenic beauty with .75 construction cost, showing location of optinum road path between A and B.



THOMAS CREEK COMPOSITE MAP
(ECONOMIC=.50 SCENIC QUALITY=.50)

ABOVE MAP HAS A MINIMUM OF: 0.000
MAXIMUM OF: 33000.000

VALUE RANGE FOR EACH LEVEL

MINIMUM	0.000	3300.000	6600.000	9900.000	13200.000	16500.000	19800.000	23100.000	26400.000	29700.000
MAXIMUM	3300.000	6600.000	9900.000	13200.000	16500.000	19800.000	23100.000	26400.000	29700.000	33000.000
CELLS	3	190	729	1547	1157	886	364	105	17	3
ACRFAGE	.36	22.63	86.83	184.26	137.80	105.53	43.35	12.51	2.02	.36
HECTARS	.14	9.16	35.15	74.59	55.79	42.72	17.55	5.06	.82	.14
SQ.MILES	.0006	.0354	.1357	.2879	.2153	.1649	.0677	.0195	.0032	.0006
PERCENT	.06	3.80	14.58	30.93	23.14	17.72	7.28	2.10	.34	.06

SYMBOLS FOR DATA LEVELS

TOTAL AREAS: 5001. CELLS 595.65 ACRES 241.14 HECTARES .93 SQUARE MILES

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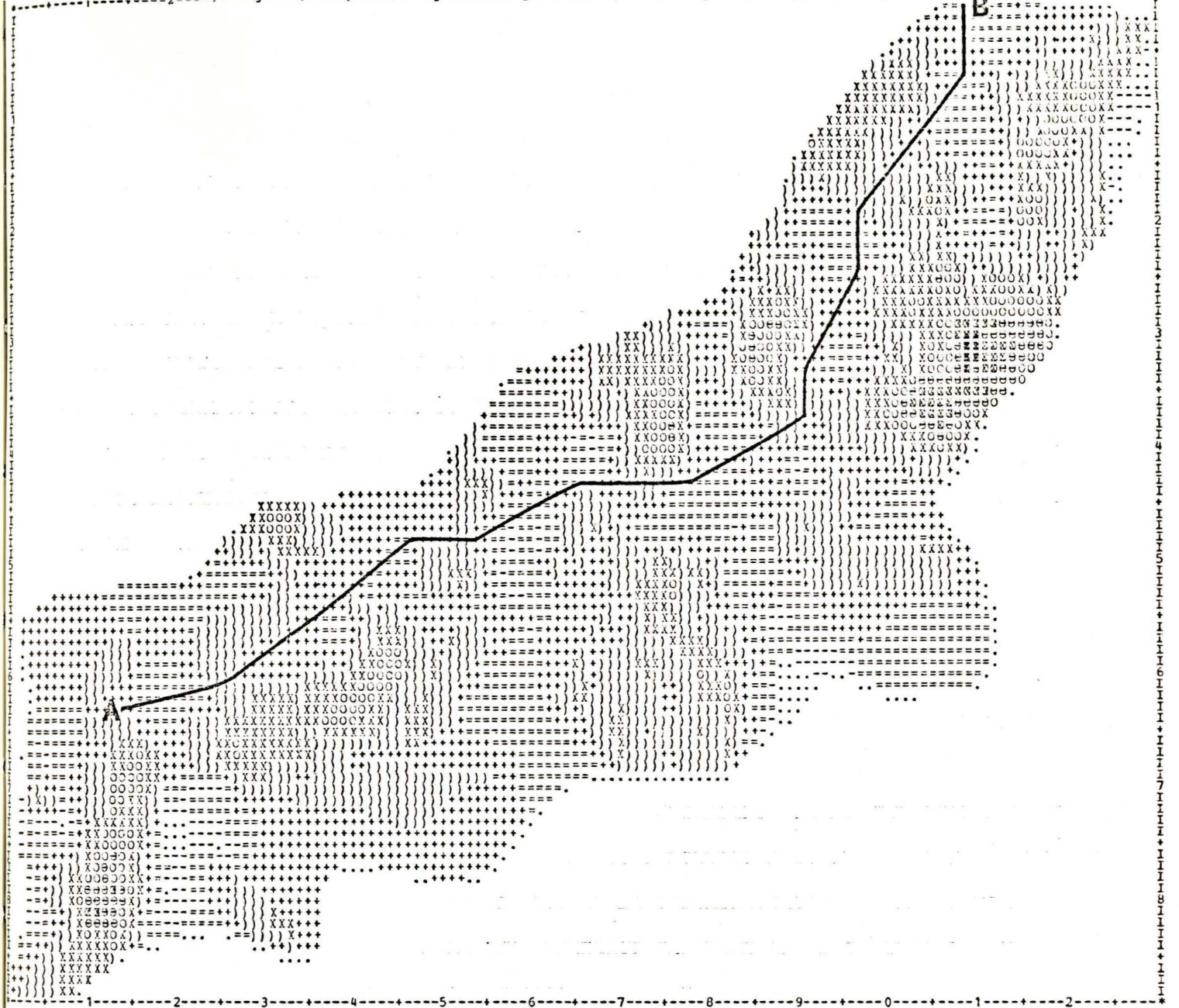
END COMPLEX

Figure 7. Composite of .50 scenic beauty and .50 construction cost, showing optinum road path between A and B.



THOMAS CREEK COMPOSITE MAP
(ECONOMIC=.25 SCENIC QUALITY=.75)

ABOVE MAP HAS A MINIMUM OF: 0.000
MAXIMUM OF: 33000.000

VALUE RANGE FOR EACH LEVEL

MINIMUM	0.000	3300.000	6600.000	9900.000	13200.000	16500.000	19800.000	23100.000	26400.000	29700.000
MAXIMUM	3300.000	6600.000	9900.000	13200.000	16500.000	19800.000	23100.000	26400.000	29700.000	33000.000
CELLS	168	128	942	1551	1240	633	221	75	36	7
ACREAGE	20.01	15.25	112.20	184.73	147.69	75.39	26.32	8.93	4.29	.83
HECTARS	8.10	6.17	45.42	74.79	59.79	30.52	10.66	3.62	1.74	.34
SQ.MILES	.0313	.0238	.1753	.2885	.2308	.1178	.0411	.0140	.0067	.0013
PERCENT	3.36	2.56	18.84	31.01	24.80	12.66	4.42	1.50	.72	.14

SYMBOLS FOR DATA LEVELS

TOTAL AREAS: 5001. CELLS 595.65 ACRES 241.14 HECTARES .93 SQUARE MILES

THIS MAP PRE
AND COMPLEX

Figure 8. Composite map of .75 scenic beauty with .25 construction cost showing location of optinum road path between A and B.

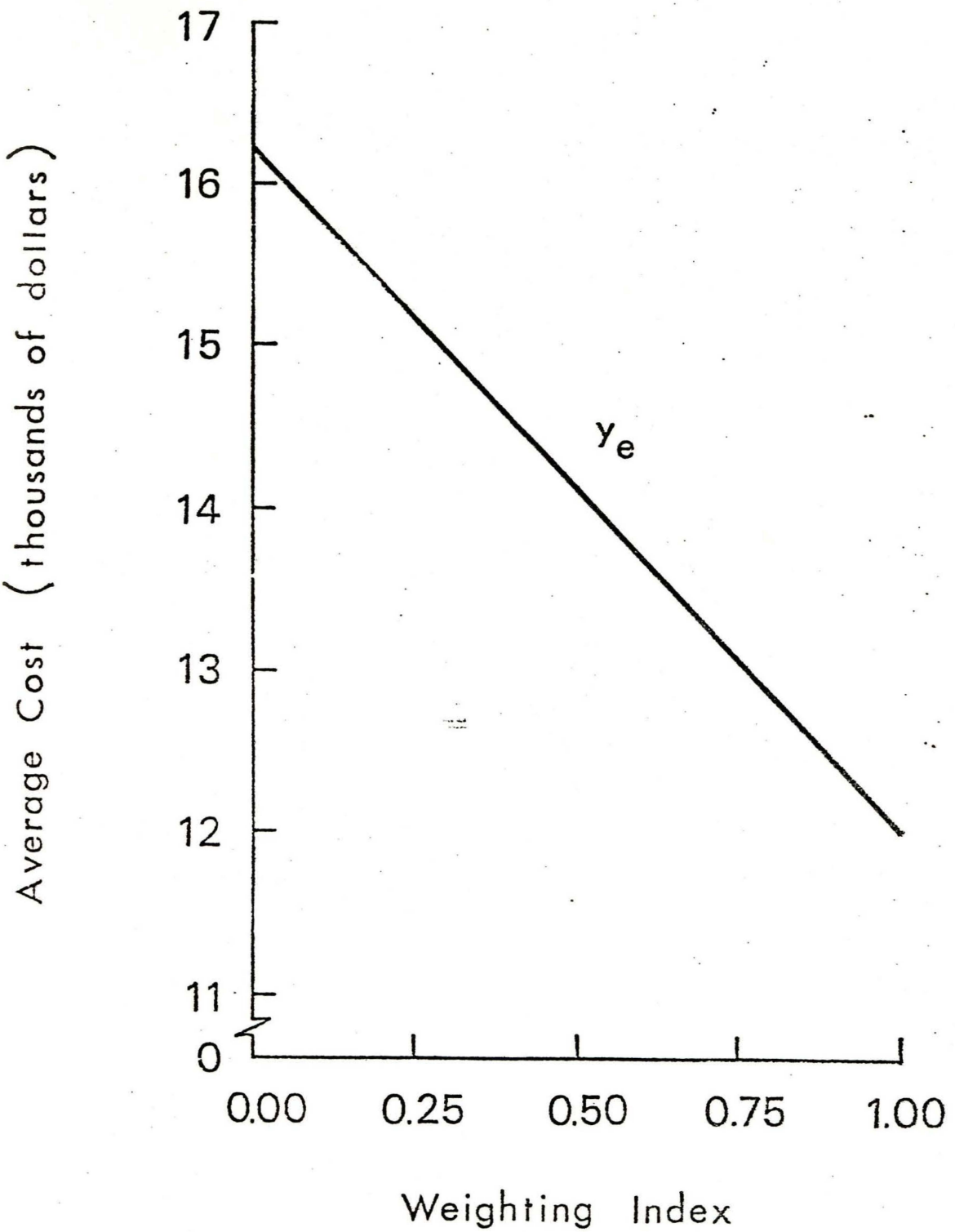


Figure 9. Average economic cost, per mile for five paths.

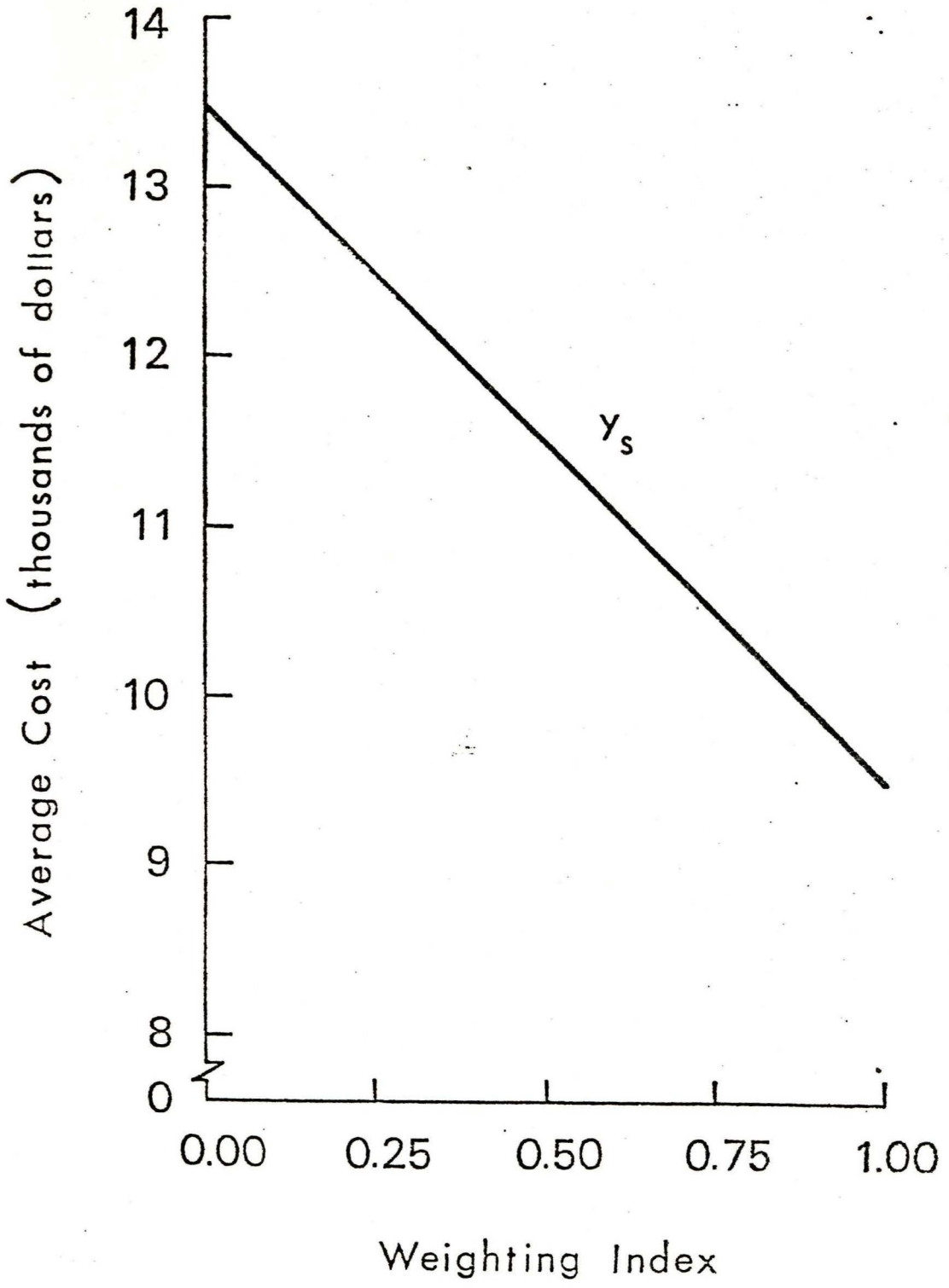


Figure 10. Average scenic beauty cost, per mile, for five paths.

Stand Number	slope 0-5%	5-15%	15-25%	25-45%	45-65%	>65%
1 & 4	$ 8,310	$10,500	$13,430	$17,900	$26,100	$30,000
2 & 3	9,821	12,409	15,871	21,155	30,846	33,000
5	10,576	13,364	17,092	22,782	33,218	35,000

Table 1. Total construction cost per mile (clearing excavation + Culvert).

Path	Surface	Total Econ. Cost	Ave. Econ. Cost	Total Scenic B. Cost	Ave. Scenic B. Cost
2	1.0E, 0.0S	30,479	11,974	34,266	13,462
4	.75E, .25S	30,310	12,906	26,449	11,262
5	.50E, .50S	28,567	12,164	25,462	10,842
3	.25E, .75S	35,265	15,016	23,095	9,834
1	0.0E, 1.0S	35,332	16,194	20,679	9,478

Table 2. Total cost and average cost for five road paths.